Fabrication of micro structures on curve surface by X-ray lithography

Yigui Li[1], Susumu Sugiyama[2]

Abstract

We demonstrate experimentally the x-ray lithography techniques to fabricate micro structures on curved surfaces such as convex and cylinder surfaces. In order to realize fabricate micro structures on curved surface, two x-ray lithography methods are described. One method is double x-ray exposures method with moving resist stage, the other is flexible mask on curved surface with rotating the resist stage. We also describe two new methods for fabricating a curved surface. One is direct x-ray exposure and the curved surface was obtained by using x-ray Gaussian intensity distribution without LIGA mask. The other one is to produce the concave surface by PCT (Plane Cross section Transfer) method. We believed that the two techniques can also transfer large area submicron size patterns, with a continuous surface relief, onto a curved surface.

[1]*Research Organization of Science and Engineering, Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan*

[2]*Department of Micro system, Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan*

1. Introduction

Micro structures have wide applications in many areas such as micro mechanical parts, optical elements, bio-chip and quantum electronics. Micro structures on curved surfaces such as convex and concave lens (mirrors) became more and more important for optical applications. Examples are the measurement of convex secondary mirror or ultraviolet spectroscopic instruments [1, 2]. There are many ways to fabricate diffractive optical elements, including focused ion beam direct milling [3], melting photo resist[4], e-beam direct writing[5] and combining laser direct writing and lithography techniques [6], laser direct writing[7]. Few methods, however, apply to concave or convex lenses, and the list thins further if the element requires precise alignment and high resolution. Applications that require such precision could benefit from recent experiments. The technique cannot produce nanometer patterns because the gap between the curve surface and the LIGA (the German acronym for lithography, electrodepositing and molding), mask. LIGA mask has the absorber structure which is copied into resist layers by using synchrotron radiation. Usually, poly-methylmethacrylate (PMMA) is used as resist material.

We have realized to fabricate micro structures on curved surface using two x-ray lithography methods. One method is double x-ray exposures method with moving resist stage, the other is flexible mask on curved surface with rotating the resist stage. For fabricating a curved surface, there are two x-ray lithography methods. One is direct x-ray exposure; the curved surface was obtained by using x-ray Gaussian intensity distribution without LIGA mask. The other one is to produce the concave surface by PCT (Plane Cross section Transfer) method.

2. Double x-ray exposure method with moving resist stage

The one method of fabricating micro structures on PMMA plate is double x-ray exposure method. In the first exposure, the concave cylinder lens was fabricated by PCT exposure on PMMA plate with a semi-circle pattern x-ray mask. Fig.1 illustrates the semi-circle mask pattern for fabricate the cylinder surface by a moving x-ray exposure system. It should be noted that we used a resist stage movement (70mm in x-direction, 70mm in z-direction) and movement was controlled by computer to a precision of 1 µm in x,z-direction. On the x-ray lithography, the position of the mask is fixed and the substrate stage is moving at a speed of 2µm/sec.

In order to obtain a cylindrical surface, an x-ray lithography mask with three semi-circle patterns with a diameter of 500µm is fabricated shown in Fig.1. X-ray mask has been made of Au and polyimide layers with the thickness of 3.5 µm and 50 µm respectively. The vertical movement (Z-direction) of the resist stage in the exposure chamber forms microstructures and gradually enlarges the exposed area of the PMMA. Since the X-ray absorption profiles in the PMMA is relevant to the area of absorber on X-ray mask, the cross-section of patterns on X-ray mask formed similar structure on PMMA whilst resulted in 3-dimension. The exposed depth in PMMA depends on X-ray dosage and the absorption coefficient of the PMMA sheet. Depth of the structures after developing can be predicted by deposited X-ray doses (controlled by exposure time and scanning speed).

The line and space pattern on cylinder lens surface is shown in Fig.2 by the double x-ray moving substrate stage method. The height of the cylinder lens is about 100µm after 0.03Ahour dose of x-ray exposure. And the second one, the sample is with 90degree rotation; expose in the same x-ray dose with a line and space grating pattern in LIGA mask, the grating is formed. GG developer (2-(2-butoxy-ethox) ethanol 60%, Morpholine 20%, Ethanolamine

5%, DI water 15%) is used for 2 hour developing , and next rinse I(2-(2-butoxy-ethox) ethanol 80%, DI water 20%) for 20min, rinse II(DI water) for 5min. The developing temperature and stir rpm is constant at 37degree, 200rpm.

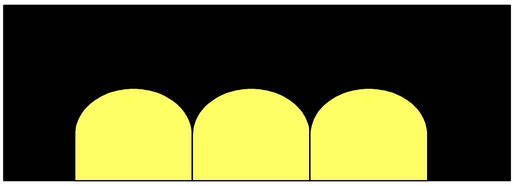

Fig.1 Semi-circle pattern LIGA mask for cylinder lens

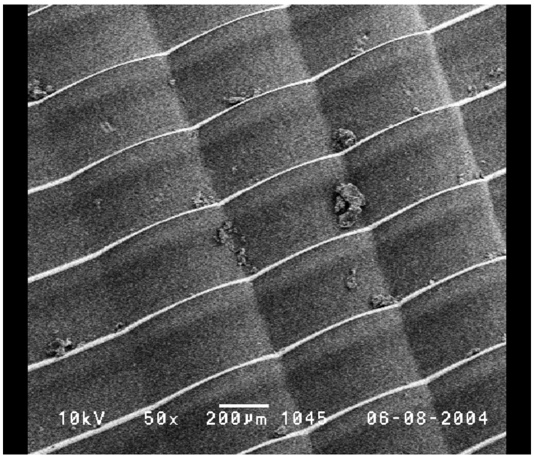

Fig.2 Fabricated cylinder lens using the mask shown in Fig.1

For fabricating a curved surface, the other method is direct x-ray exposure; the curved surface was obtained by using x-ray Gaussian intensity distribution without LIGA mask. Fig.3 shows the x-ray Gaussian intensity distribution of x-ray source in Ritsumeikan University. Based on the distribution, a different aspect ratio micro structure is obtained (Fig.4).

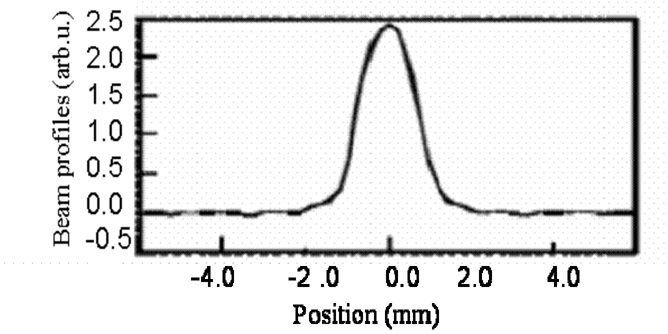

Fig. 3 X-ray Gaussian intensity distribution of x-ray source in Ritsumeikan University

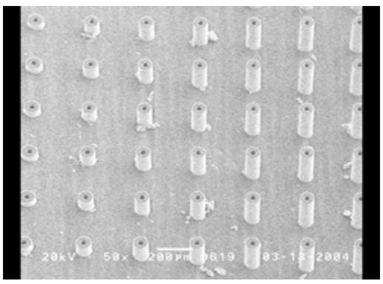

Fig. 4 Different aspect ratio structures obtained by the Gaussian intensity distribution of the x-ray source

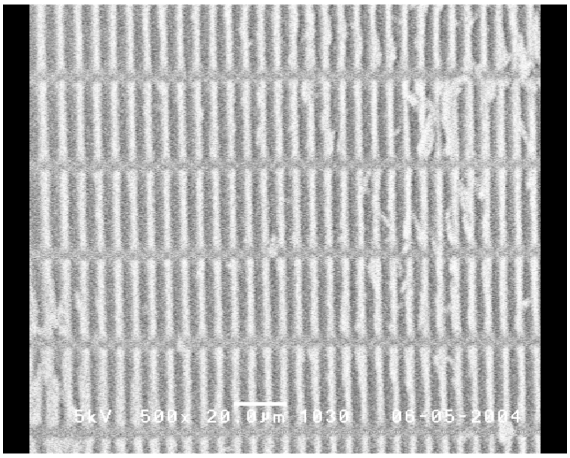

Fig.5 Micro gratings on a convex surface

Fig.5 shows micro gratings on a convex surface. The grating pitch is 6µm, and about 10µm in height. Considering fabrication condition, the concave surface is obtained by x-ray exposure without LIGA mask. Because the intensity distribution of x-ray exposure beam is the Gaussian distribution, therefore, we can obtain a curve surface (30mm x 5 mm) after development. Secondly, use a line and space grating LIGA mask and do x-ray exposure by moving substrate stage (with a speed of 2mm/sec), a line and space grating is formed.

3. Flexible mask on curved surface with rotating the resist stage

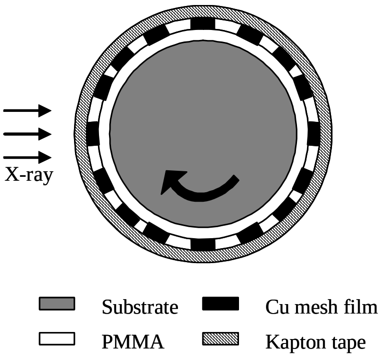

Fig.6 Rotation exposure principle

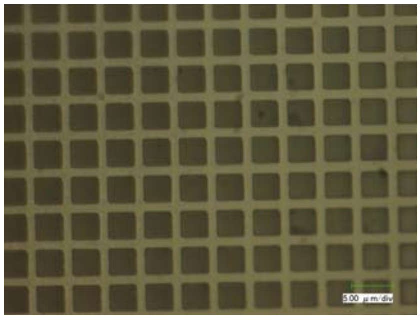

Fig.7 Copper mesh as LIGA mask

We have also proposed an x-ray lithography method to fabricate the micro or nano structure on cylinder or sphere surface as shown in Fig.6. The system consists of membrane (the Kapton tape film here) and the absorber structure (copper mesh shown in Fig.7) as x-ray mask and PMMA resist on curve substrate. It can transfer micro or nanometer patterns in a large area to PMMA resist on cylinder or sphere substrate because of the flexible copper mesh film as LIGA mask absorber. By rotating the cylinder or sphere substrate, the whole surfaces can exposure. We have done the experiment to confirm the possibility by the proposed method. In our example fabrication process, the PMMA cylinder functions as substrate and PMMA resist. Fig.8 shows the scanning electron microscope photography of micro gratings on a PMMA cylinder surface. The grating pitch is 12.7µm, and about 10µm in depth. The sample PMMA cylinder size is 20mm in height and 6mm in diameter. The dosage is about 0.06Ahour and the development time is one hour. The nano or submicron structure could be fabricated when the mesh with nano or submicron structure available because the gap between the mask and PMMA resist is almost zero.

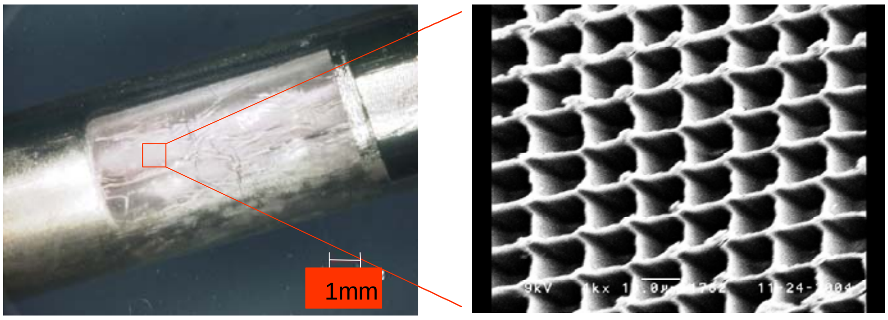

Fig.8 Photography of micro grating on cylinder surface

4. Conclusions

We have proposed and confirmed two methods for fabricating micro structures on curved surface by using x-ray lithography. To our knowledge this is the first time that moving resist stage x-ray lithography has been used to transfer a large area micro pattern onto a curved surface. It is believed that this technique can also transfer large DOE patterns with a continuous surface relief onto a convex or concave surface. We also proposed and confirmed two methods to manufacture curved surface on PMMA plate, i.e. the Gaussian intensity distribution method and the PCT method. The fabricated structure can be employed as molds for further batch-processing by using electro-deposition process.

Acknowledgements

This work was supported by the Kyoto Nano Cluster Project and by NFSC Foundation (grant number 60377014) of China. Specially, the SR Center of Ritsumeikan University is gratefully acknowledged for exposure of x-ray.

REFERENCES

1. J.H.Burge, D.S.Anderson, T.D.Milster, and C.L.Vernold, “Measurement of a convex secondary mirror using a holographic test plat,” Proc. SPIE 2199,193-198,1994.
2. T.Harada, S.Moriyama, and T.Kita, “Mechanically Ruled Stigmatic Concave Gratings,” Japanese Journal of Applied Physics, **14**, 175-179, 1974.
3. Y.Fu, N.Bryan “Investigation of diffractive optical element fabricated on diamond film by use of focused ion beam direct milling,” Optical Engineering, **42**, 2214–2217, 2003.
4. D. Daly, Microlens Arrays, Taylor & Francis (London and New York, 2001).
5. E.Kley, B.Schnabel, U.Zeitner “E-Beam lithography -an efficient tool for the fabrication of diffractive and micro optical elements”, Proc. SPIE 3008, 222-228, 1997.
6. Y. Xie, Z. Lu, F. Li, J. Zhao and Z. Weng “Lithographic fabrication of large diffractive optical elements on a concave lens surface” OPTICS EXPRESS **10,** 1043-1047, 2002.
7. W. X. Yu, X. -C. Yuan, N. Q. Ngo, W. X. Que, W. C. Cheong and V. Koudriachov “Single-step fabrication of continuous surface relief micro-optical elements in hybrid sol-gel glass by laser direct writing” OPTICS EXPRESS ,**10,**443-448,2002.